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BRIEFING PAPER
RADIOLOGICAL ASSESSMENT/CLEANUP CRITERIA
FLORIDA PHOSPHATE MINING INITIATIVE
May 16, 2005

Objective

The objective of this briefing is to clarify previous discussions and impressions about the varying approaches to assessing and quantifying risks to human health arising from exposures to "Technically Enhanced Naturally Occurring Radioactive Materials" (TENORM). This briefing also proposes an assessment/response approach that is consistent with widely recognized international and national radiation protection guidance, and compliant with the Comprehensive, Environmental Response, Compensation, and Liability Act (CERCLA) and the National Contingency Plan (NCP).

Background

This briefing is a continuation of efforts to develop a strategy to address the potential for current and future impacts to human health posed by TENORM originating from phosphate mining activities in the west-central Florida area. The extent of the mineable limit is approximately 2150 square-miles (mi^2). Within this mineable limit, there are several stages of mining with correspondingly different exposure routes, degrees of risk, and protective measures that may be needed. For example, it is estimated that within the mineable limit, there are approximately 11mi^2 of mined land that has been developed for residential use. These areas pose the potential for current exposures and risks to human health from exposures to TENORM. These exposures may be comprised of the inhalation of radon gas, direct exposures to gamma radiation, or ingestion of radium contaminated soils. A second category includes approximately 215 mi^2 of land that has been mined, but not developed. This mined, non-developed, category has the potential to pose the same potential risks to human health, but since there are no existing developments, a broader range of protective measures could be available. The final category includes approximately 1924 mi^2 of land that is either currently being mined or could be mined in the future. This differs from the mined, non-developed, category in that mining activities are either underway or yet to be started, and therefore, any potential risk that might occur would be from the development of the property at some point in the distant future. This category would thereby have even greater flexibility in developing measures that would be protective of human health.

Potential risks to human health from exposures to TENORM from the phosphate mining can be further categorized into current and future exposures. Each of these categories contains technical, socio-economic, and regulatory considerations that are unique to each. Probably the most fundamental difference is the type and timing of protective measures that can be employed due to the fact that areas currently occupied will require a timely, more aggressive response, where as areas not currently developed can be addressed over-time with less intrusive measures.

This briefing, therefore, attempts to address the appropriateness of assessment and cleanup criteria for TENORM and to address the appropriateness of protective measures relative to the timing and degree of potential exposure, as well as, acknowledging the need to balance socio-economic considerations with protectiveness. For the purposes of this briefing, it is assumed that any actions taken pursuant to CERCLA will need to comply with ARARs and the CERCLA risk range.

TENORM Assessment/Cleanup Criteria Discussion

Thus far, there as been extensive discussions among EPA (Region 4, OSWER, ORIA); the State of Florida (DEP and DOH); and ATSDR regarding criteria that could serve as a threshold for determining whether a response is needed, and if so, the appropriate level to be used for cleanup. Below is a review of the differing criteria and approaches to address TENORM.

EPA Approach

EPA's approach to addressing radiological contamination under Superfund is clearly presented in OSWER Directives titled *"Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination", OSWER No. 9200.4-18, August 22, 1997* and *"Use of Soil Cleanup Criteria in 40 CFR Part 192 as Remedial Goals for CERCLA Sites", OSWER No. 9200.4-25, February 12, 1998.* As with chemical contaminants, remedies intended to address risks from radioactive materials are to be compliant with the CERCLA carcinogenic risk range of 10^{-4} to 10^{-6} as established in the NCP and are to be compliant with ARARs. The primary source of ARARs for consideration in this case arises from the Uranium Mill Tailings Radiation Control Act (UMTRCA) (40 CFR 192). UMTRCA establishes levels of 5pCi/g above background for Ra^{226} in soil and 20 μR/hr above background for indoor gamma radiation levels.

State Approach

The State of Florida has different approaches to regulates chemical and radiological contaminants. The Department of Environmental Protection (DEP) is charged with regulating chemical contaminants and generally requires that environmental cleanups be protective of carcinogenic risk of 10^{-6}. The Department of Health (DOH) is charged with the responsibility of regulating

radiological matters within the State. The only applicable State standard that is promulgated and could be used as a criteria to address the potential risks from TENORM is a value of 20 μR/hr, including background, for indoor gamma radiation levels (FAC 64E-5.1001). The Department of Health, however, has advised EPA that this is a guidance criteria and not enforceable.

DOH has primarily relied on guidelines published by the National Council on Radiation Protection and Measurements in its publication titled "*Limitation of Exposure to Ionizing Radiation", NCRP Report No. 116, March 31, 1993*, to develop recommendations to EPA to address potential risks to human health from TENORM. In addition to the NCRP guidelines, DOH had available to it TENORM guidelines prepared by the Conference of Radiation Control Program Directors (CRCPD), Part N. These standards represent the collective opinions of the State's regarding TENORM. However, only the NRCRP guidelines were incorporated into DOH's recommendation.

In February 2005, DOH, in consultation with ATSDR, proposed an approach titled "Residential Survey Plan" that could be used to evaluate potential TENORM impacts in residential areas. This approach proposed that further consideration be given to properties that had initial radiological screening values exceeding 30 uR/hr above background. DOH reports that NCRP recommends that remedial action be undertaken when radon gas levels for total decay products exceed and annual average of 7×10^{-3} Jhm $^{-3}$ (i.e., 8 pCi/l) and when continuous exposures from natural sources exceed five times the average, 5 mSv (500 mRem) annually. From these recommendations, DOH recommended the following approaches for gamma and radon exposures:

Gamma Exposures

- Dose level below 100 mRem/yr, no action required.
- Dose levels between 100 and 500 mRem/yr, further assessment provided along with educational information to homeowner to reduce exposures.
- Radiation dose level above 500 mRem/yr, EPA will perform necessary remediation.

Radon Gas Exposures

- Below 4 pCi/l, no action required.
- Between 4 to 8 pCi/l, results to be provided to homeowner with recommendation to perform remediation.
- Above 8 pCi/l, EPA would perform remediation.

Further discussions with DOH revealed that although the State has no promulgated criteria for the protection of public health from TENORM exposure, it recommends adopting an approach based on the guidelines established by the NCRP in publication No. 116.

Discussion of Criteria

Numerous discussions have occurred between EPA and the State of Florida in an effort to reconcile the divergent points of view with respect to the risks to public health from exposures to TENORM. EPA's approach to evaluating radiation risks is the same as its risk-based approach to chemical carcinogens. DOH has indicated that it supports a dose-based approach and the guidelines outlined in NCRP Report No. 116. Subsequent to these discussions, there seems to have developed a misconception regarding what might be considered main-stream in the regulatory and radiation protection community. This misconception further suggests that EPA's approach may be "out-of-step" with the rest of the radiation protection community. A review, however, a review of TENORM criteria used by other Federal Agencies, States and Scientific organizations suggest that EPA's approach to the protection of human health from exposures to TENORM is indeed main-stream. Table 1 summarizes the various criteria.

From a review of criteria summarized in Table 1, several observations can be made:

- Among the Federal, State, and scientific organizations reviewed, the State of Florida is the only one without specific criteria to address NORM or TENORM.
- The State of Florida appears to have miss-applied the guidelines from NCRP Report No. 116 in developing its February 2005 recommendations to EPA. A review of the NCRP Report No. 116 suggests that the basic foundation for the protection of public health is to limit radiation levels to those comparable or less than those risks in safe industries. The NCRP recommends that "the radiation- protection system should result in an average annual risk of fatal cancer of 10^{-4} or less". The NCRP also recommends limiting the average annual dose for continuous exposures to 100 mRem/yr for continuous exposures. The State of Florida recommended a threshold of 500 mRem/yr. The NCRP frequently emphasized the goal of reducing risks to as low as reasonably achievable, but also recommended that societal needs and costs also be balanced with the incremental reduction in risk.
- There seems to be wide spread acceptance and practice of the use of a radium criterion of 5 pCi/g among Federal and State programs. Some State programs have further refined the use of the 5 pCi/g relative to radon gas emissions.
- There also seems to be wide spread acceptance of the annual dose limit of 100 mRem/yr. This dose limit, however, is not incorporated into OSWER guidance.

In summary, there is strong support for the use of a radium soil criterion and an annual

dose limit to address the protection of public health relative to exposures to NORM and TENORM. In addition, CERCLA and the NCP requires that remedies be protective of human health and comply with ARARs. In this case, remedies would need to comply with carcinogenic risk range of 10^{-4} to 10^{-6}. The subsequent section discusses an approach that is intended to both be compliant with CERCLA and the NCP as well as incorporate mainstream radiation protection guidelines.

Table 1 - Comparison of TENORM Criteria for the Protection of Public Health					
Agency/State	Criteria				Notes
	Dose (mRem/yr)	Exposure Rate (μR/hr)	Ra^{226} - Soil (pCi/g)	Chronic Risk	
Federal Agencies					
EPA, OSWER Dir. 9200.4-18; 9200.4-25	–	–	–	10^{-4} to 10^{-6}	OSWER's over-riding criteria is compliance with the CERCLA risk range. UMTRAC is routinely applied as an ARAR.
EPA, ORIA	100	20	5	–	Source: Draft National Guidance; 40 CFR 192 (UMTRCA).
DOD	–	–	5/15	–	Generally incorporates 40 CFR 192 as ARAR. 5 pCi/g from surface to 15cm below surface; 15 pCi/g below 15 cm.
DOE Order No. 5400.5	100	–	5/15	ALARA	Although DOE's Order 5400.5 incorporates ALARA (as low as reasonably achievable) in practice cleanups often incorporate 40 CFR 192 as an ARAR. 5 pCi/g from surface to 15cm below surface; 15 pCi/g below 15 cm.
ATSDR	100	–	–	–	ATSDR has historically recommended a Minimum Risk Levels of 100 mRem/yr for radiation. MRLs, however, are only designed to address non-cancer health effects. Source:http://atsdr1.atsdr.cdc.gov:8080/mrls.html

Table 1 (Continued)					
State Agencies					
Florida, FAC 64E-5.1001	–	20	–	–	FAC establishes the 20 μR/hr (including background) as an indoor criterion for the protection against radon gas exposure. The State has advised that this criteria has only been used as a guidance value.
Alabama	–	50	5	–	Regulates NORM if the source exceeds 50 μR/hr (including bkg.) or Ra exceeds 5 pCi/g.
Georgia	–	50	30/5	–	Radon gas < 20 pCi/m^2 /s - 30 pCi/g; Radon gas ≥ 20 pCi/m^2 /s - 5 pCi/g
Mississippi	–	50	30/5	–	Same as GA
South Carolina	–	50	30/5	–	Same as GA and MS
Louisiana		50	5/15/30	–	5 pCi/g for upper 15cm; 15 pCi/g below 15 cm; 30 pCi/g below 15 cm if the dose does not exceed 100 mRem/yr.
Texas	–	50	30/5	–	Same as GA, MS and SC
Scientific Organizations					
ICRP Report No.60, Principals for Limiting Exposure to the Public to Natural Resources of Radiation	100/500	–	–	–	ICRP recommends limiting doses to 100 mRem/yr for repeated exposure over prolonged periods, and 500 mRem/yr for any year.

Table 1 (Continued)					
NCRP - General Population, NCRP Report No. 116	100/500	–	–	10^{-4} or less (ALARA)	NCRP recommends that radiation protection for the general public should be comparable to or less than those in safe industries; radiation protection for the public should result in an average annual cancer risk of 10^{-4} or less. NCRP recommends that doses be limited to 100 mRem/y for continuous exposure and 500 mRem/yr for infrequent exposure. NCRP also recommends incorporating ARARA to balance societal needs and cost with protection of public health.
NCRP - Embro-fetus, NCRP Report No. 116	50 (mRem/mo)	–	–	–	Due to the sensitivity of the embryo-fetus for mental retardation and cancer, NCRP recommends for occupational exposures the monthly dose not exceed 50 mRem.
CRCPD, Conference of Radiation Control Program Directors - Implementation Guidance for Regulation and Licensing of Technology TENORM, Part N of the Suggested State Regulations for Control of Radiation	100	–	5	–	CRCPD provides radiation guidelines to States. Incorporation of guidelines is voluntary. 100 mRem/yr is applied as an exemption level for which releases below this level do not require permitting/regulation.

Proposed Strategy and Assessment/Response Criteria

As discussed in the background section of this briefing, potential risks to human health from TENORM from phosphate mining has the potential to affect both current and future uses. Relative to the amount of land that had been mined and developed for residential use, the amount of land is currently being mined, or that could be mined in the future, and used for residential could pose a significantly large problem than the currently developed areas. For example, of the 226 mi^2 of land that has been mined only about 5% of the land has been developed for residential use. Based on a residential density of two homes per acre, this would equate to approximately 14,000 homes that could overly areas with elevated radium and radiation levels. However, if over the next 30 to 50 years, phosphate mining continues and all of the mineable limit is mined, and 5% of the area is eventually developed for residential purposes, its conceivable that the number of homes overlying areas with elevated radium and radiation levels could easily swell to over 2,000,000 homes. This correlation is explained mainly to illustrate that while an important consideration are the potential risks to current residents, potential risks to future residents could pose an even larger public health threat, if not addressed. Its, therefore, appropriate that any approaches to address potential health impacts from exposures to TENORM address both current and future residential use scenarios.

The approaches described below mainly address the criteria and mechanisms to address potential risks once an area of concern has been established. There has been significant discussions and plans developed (i.e., *Pilot Study Aerial Radiological Survey, Polk and Hillsborough Counties, Florida, Final Work Plan, Argonne National Laboratory, April 2004*) that provide suitable approaches for the initial identification and characterization and of areas with elevated levels of radiation.

Although future residential use scenarios could eventually pose a greater public health threat if not address, the current residential use scenarios presently pose the greatest challenges. Data collected thus far suggests that current residents with elevated levels of radium and radiation could be exposed to excess cancer risks in the range of 10^{-3}, and upwards to 10^{-2}. The current Superfund paradigm would suggest that this is an unacceptable risk level and that actions should be taken to reduce risk levels to within the CERCLA risk range of 10^{-4} to 10^{-6}, or in this case, background which is presently at 10^{-4} due to natural radiation sources. Traditional remedial measures to reduce risks to a resident could include removal or shielding of the source, or relocation of the resident. Remedial measures of this nature would be very costly in terms of actual cleanup costs and less tangible costs due to socio-econmomic impacts, but may only result in an order of magnitude reduction in risk.

In contrast, future risks to human health from exposure to TENORM could easily and cost effectively be controlled through institutional controls (ICs). The ICs would not prohibit future use of the land for residential purposes, but would set criteria that would need to be met for the protection public health based on the nature of the use. The ICs

could be incorporated into the future land use at comparatively less cost than for areas currently developed. In this case, the same amount of reduction in risk is achieved as with the currently developed area, but at a substantially lower cost.

This relationship between current and future uses, response costs, and relative reduction in risk is presented to high-light the importance of 1) developing practicable response actions that are protective of human health, but balance the cost with the incremental reduction in risk; and 2) addressing potential risks to future residents while the opportunity exists to incorporate risk reduction measures in a cost-effective manner.

Current-Use Residential Scenarios

The most challenging issue for the current-use scenario is the development of response actions that are compliant with 40 CFR §300.430 (i.e., protective of human health (10^{-4} to 10^{-6} risk range) and compliant with ARARs) and that also balances the actual and non-tangible cost with the reduction in risk. To successfully meet this challenge, a variety of tools, including, risk management, alternative remedial approaches, and site-specific response criteria will need to be employed.

An important issue for consideration is the concept of risk management. Risk to human health from naturally occurring radioactive materials is presently at approximately 10^{-4} for carcinogens. Since Superfund had traditionally treated background as a limit below which additional cleanup efforts would not be conducted, a risk level of 10^{-4} would be considered protective of human health and the goal that any response actions would need to achieve. Data collected thus far by EPA and the State of Florida suggest that exceedances of this criterion would be in the 10^{-3} range with some higher levels approaching 10^{-2}. Therefore, response actions would generally need to reduce risk levels by one to two orders of magnitude to be considered protective.

The second issue for consideration is the concept of balancing the degree of risk reduction with cleanup cost and socio-economic impacts. Due to the nature of the contaminant, the need to deal with existing structures, topography, construction methods, and the cost of reducing the risk levels using traditional remedial methods would be very costly. Some initial estimates for excavation and off-site disposal of contaminated soil for a one-half acre lot are upwards of $500,000. In addition to the cost of remediation, there are less tangible societal costs that must be considered. Societal costs could be related to depreciated property values, local economic effects, and psychological affects of living in a contaminated area.

Because of the comparatively high remedial and societal costs, its critical that the actual risks to individual residents be fully evaluated and understood prior to

undertaking any remedial action. This is exclusive of clearly elevated levels of radioactivity that warrant response actions on an emergency basis. For example, remedial actions to reduce risks are often implemented on the basis of a risk assessment for a group of generalized scenarios designed to represent risk to an average person. Alternatively, remedial actions can be taken on the basis of the exceedance of an ARAR. In this case, however, it would be prudent, and arguably more cost effective to conduct a risk-based and dose-based assessment for individual residents prior to making decisions whether or not response actions are needed.

RESRAD (Residual Radioactivity) is a modeling program developed by Argonne National Laboratory, on behalf of DOE, that could be employed to quickly and cost-effectively evaluate site-specific risks. RESRAD is widely accepted and can evaluate both risk-based and dose-based potential health effects. An overview of RESRAD can be found at Argonne National Laboratory's web site http://www.ead.anl.gov/project/dsp_topicdetail.cfm?topicid=21. Conceptually, once a property had been identified through an aerial and ground-based radiological survey as an area of concern (i.e., gamma radiation levels $\geq$20 μR/hr), an investigation of the individual property would be conducted to collect contaminant parameters (i.e., Ra concentration, radon gas flux, radiation levels), exposure parameters, environmental parameters, etc. This information would then be used along with RESRAD to develop estimates of risk for individual properties. This information could also be used to conduct "risk optimization" scenarios to identify and evaluate areas that have the greatest influence on risk. Cost-effective response actions could then be designed to address those areas posing the greatest risk.

For example, situations may arise where the initial radiological assessments indicate radioactivity levels that exceed the 20 μR/hr screening level and subsequent soil monitoring of the area documents generalized exceedances of the 5 pCi/g ARAR. Ordinarily, this would indicated that response actions are warranted for the area in order to reduce the levels to comply with ARARs and an acceptable CERCLA risk level. However, evaluation of individual properties and calculation of risk levels at individual properties would likely show variations in the distribution of radium levels in soil and would also high-light areas of contamination or exposure pathways that pose the greatest influence on risk. Depending on the site-specific circumstances, the site-specific risks may be reduced through targeting areas of soil contamination or exposure pathway that pose the greatest risk.

It is also noteworthy that when applying the UMTRCA ARAR for Ra^{226} the soil sampling unit is not to be averaged over an area greater than 100m^2 in size. Since the promulgation of UMTRAC in 1978, additional statistical methods have been developed that improve the ability to assess the distribution of radium in the

soil. MARSSIM is a statistically based assessment approach that provides for the averaging of contaminant levels over a survey unit (i.e., entire property) versus a 100 m^2 area. MARSSIM coupled with RESRAD could be used to conduct "risk optimization" scenarios that could be used to determine the exposure pathway and areas of contamination that have the greatest influence on risk, and thereby should have the greatest priority for abatement.

On the other hand, the site-specific risk assessment may document the presence of wide-spread contamination in the yard, elevated levels of gamma radiation and radon gas inside the home, and unacceptable levels of risk. In certain cases, the only way to effectively reduce these risk may be through more traditional means such as excavation and off-site disposal or relocation. Although the cost of response actions such as this will be high, EPA, the State and homeowner will have the certainty from the site-specific risk assessment that threat was severe and that costly measures were indeed necessary to mitigate these risks.

Lastly, cases may arise where although the individual risks are fully evaluated and there is documentation of an elevated risk level, the homeowner determines that the societal impacts are too costly, and chooses not to have any response work conducted. In cases such as this, no response action would be forced. EPA and the State would document the circumstances of the case and the homeowners rejection for any response actions. Future purchasers of the property would need to be protected through local real estate disclosure laws. Its unlikely that the homeowner would consent to a deed notice that documents the contaminant problems.

In summary, the approach to addressing risks under current-use residential would rely heavily on the concept of "risk optimization". Site-specific data and predictive modeling tools such as RESRAD and MARSSIM would be used to optimize the characterization of the nature and extent of contaminants and risk at individual properties. This information could then be used to develop response actions that cost-effectively target areas posing the greatest risk. While this approach would not excluded the possibility of drastic remedial measures being employed, it would ensure that they would be taken only when absolutely necessary.

Future-Use Residential Scenarios

With regard to the future-use residential scenario, the opportunity exists to achieve a significantly greater degree of reduction in future risks at significantly lower costs than for the current-use residential scenarios. This is due to the absence of existing structures and infra-structures and the fact that the amount of current residential development represents only a fraction of the amount of residential development that could occur over the next 30 to 50 years. Protective measures taken now could primarily be in the form of ICs to manage future risk.

For example, ICs in the form of deed restrictions or easements could be used to limit future use of the property in a way that would be compatible with the radiation levels remaining after the mining. Conceptually, it would be the obligation of the seller to document the radiation levels and the types of acceptable uses considered safe relative to the CERCLA risk range.

Orders with mining companies or property developers could also be used to ensure that the post-mining radiation levels and planned use did not result in risk level beyond the CERCLA risk range. Depending on the site-specific radiation levels, a property or portion thereof may be acceptable "as is" for residential use, or it may be determined that the radiation levels are too high and would result in an unacceptable risk. In that case, the owner and/or developer would need to restrict the use to less intensive use that would be compatible with the radiation levels and not exceed the CERCLA risk range. Alternatively, if the value of the property when developed for residential use exceeded the cost of clean-up, it may be cost-effective to mitigate the radiation levels and proceed with the development.

The goal of this approach would be to make the program as self-implementing as possible in that it would be the responsibility of the seller or developer to demonstrate to Federal and State governments that the land was being used in a safe manner. It would be the responsibility of the seller or developer to determine whether it would be cost-effective to reduce the radiation levels to achieved greater flexibility in the use of the property.

Summary

This briefing paper has attempted to 1) illustrate that EPA's criteria for approaching radiation protection is indeed main-stream and 2) absent in any significant changes in HQ guidance to address TENORM, offer approaches that attempt to achieve the maximum degree of risk reduction in a cost-effective manner. This briefing only contains general concepts. If embraced, these concepts would need further development for a more detailed assessment/response approach to the problem of TENORM in residential areas. Although this strategy could be further refined, the collection of data from an initial screening of the are would be necessary to develop an assessment/response strategy and to better address questions regarding overall impacts to the Superfund program and socio-economic issues.